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Electrodeposition of Actinide and Lanthanide Elements

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ELECTRODEPOSITION OF ACTINIDE AND LANTHANIDE ELEMENTS

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Abstract

Some deposition parameters for the quantitative electrodeposition of hydrolysis products of plutonium were qualitatively studied at trace concentrations of plutonium.

The hydrogen ion concentration, the current and the electrolysis time proved to be the determining factors in the quantitative electrolytic precipitation of plutonium, while other factors such as cathode material, the pretreatment of the cathode surface, the nature of the electrolytic anion, and the oxidation state of plutonium in the starting solution were found to be of less importance.

The conditions selected for quantitative electrodeposition of plutonium from slightly acid nitrate solutions on a stainless steel cathode were successfully tried also with uranium, neptunium, americium, cerium and thulium.

Details of a procedure used for plating mg amounts of plutonium and neptunium on small stainless steel cylinders are also given.

LIST OF CONTENTS

	<u>Page</u>
1. Introduction	3
2. Theoretical aspects	3
3. Experimental	4
4. Results and discussion	6
4.1 Addition of NH_3	6
4.2 Acid concentration	7
4.3 Effect of current and electrolysis time on deposition yield	8
4.4 Effect of mechanical stirring	10
4.5 Effect of temperature	12
4.6 Selected method for quantitative deposition of plutonium	12
4.7 Surface preparation effects	13
4.8 Cathode materials	14
4.9 Deposition from various acids	14
4.10 Deposition of plutonium in different oxidation states	15
4.11 Electrolytic precipitation of plutonium in the presence of foreign ions	15
4.12 Electrodeposition of uranium, neptunium, americium, cerium and thulium	16
5. Electrolytic precipitation of mg amounts of plutonium and neptunium	17

Acknowledgement

References

1. Introduction

Electrodeposition of actinide and lanthanide elements from aqueous or organic solutions on metal foils or wires by use of suitable precipitation reactions at the cathode offers a simple means of obtaining thin, uniform and good adherent films suitable for accurate measurements in the study of the nuclear properties and isotopic composition of the elements. In addition, this technique may be used successfully in radiochemical analysis, as it makes it possible to isolate submicrogram amounts of the elements quantitatively, giving sample mounts suitable for precise counting.

Most of the procedures described for electrodeposition of actinide elements rely upon the precipitation of an insoluble compound at the cathode surface. In this way sources of Ac and Th were early prepared by Hahn and Meitner [1] from aqueous solutions and by Cotelle and Haissinsky [2] from alcohol-acetone solutions. Several procedures depending on this technique have been published for electrodeposition of plutonium and other actinides from alkaline [3-5] or slightly acid [6-13] solutions. The term "molecular plating" was coined by Parker [14] to describe electrodeposition of metal compounds from organic solutions. This technique has been used successfully for preparing uniform films of Th, Pa, U, Np, Pu, Am, rare earth and several other elements [15, 16].

The present report deals with an experimental study of some parameters for the quantitative electrodeposition of plutonium from aqueous solutions. The technique developed was specifically intended for application in the radiochemical analysis of plutonium at very low concentrations in biological samples.

2. Theoretical aspects

The numerous less noble [17] lanthanide and actinide elements cannot be deposited from aqueous solutions in the form of metals. Insoluble hydrolysis products of the element can, however, be deposited on the cathode by alkalizing the solution in contact with the electrode at suitable hydrogen overpotential and appropriate pH in the electrolyte. Very little is known about the mechanism of the electrodeposition and there is no theory predicting the deposition rates. It is, however, from an exper-

imental point of view possible to predict some circumstances under which the cathodic deposit can be formed.

During electrolysis the electrochemical reaction produces a change in the concentration of the electrolysed substances near the electrode. A concentration gradient is thus set up between the surface of the electrode and the body of the solution. Diffusion of ions to and from the cathode surface takes place in this layer, while the rest of the liquid is assumed to be well stirred and of constant composition. During electrolysis of an acid solution the pH at the cathode increases with increasing current density. The removal of hydrogen ions by discharge is balanced by migration and by diffusion until the current density reaches a value at which hydrogen ions must be supplied by some mechanism other than electrolytic transport, presumably by the dissociation of water. The pH of the solution at the cathode then increases abruptly to the region in which water itself has a high buffer capacity, that is, from pH 12 upwards [18]. With an inert salt as supporting electrolyte, electroneutrality is assured and pH values high enough for most precipitation reactions can be obtained. If some other reaction capable of supplying hydrogen ions can take place a given current density corresponds to a lower pH. With a buffer consisting of a weak acid and its salt, hydrogen ions may be supplied by the dissociation of the weak acid, as the pH at the cathode approaches the pK of the acid and the pH may be expected to remain at a value in the neighbourhood of the pK even at high current densities. The favourable effect of ammonium salts on the deposition of plutonium from acid solutions found by several workers [6, 8, 9] may be due to their function both as supporting electrolyte and as a suitable buffer.

3. Experimental

Plutonium was isolated in an electrolytic cell (Fig. 1) similar to that used by Sanders & Leidt [9]. A stainless steel plate with a working area of 0.385 sq. cm was used as cathode, and the anode consisting of a plane spiral of platinum wire was fixed 5 mm above the cathode.

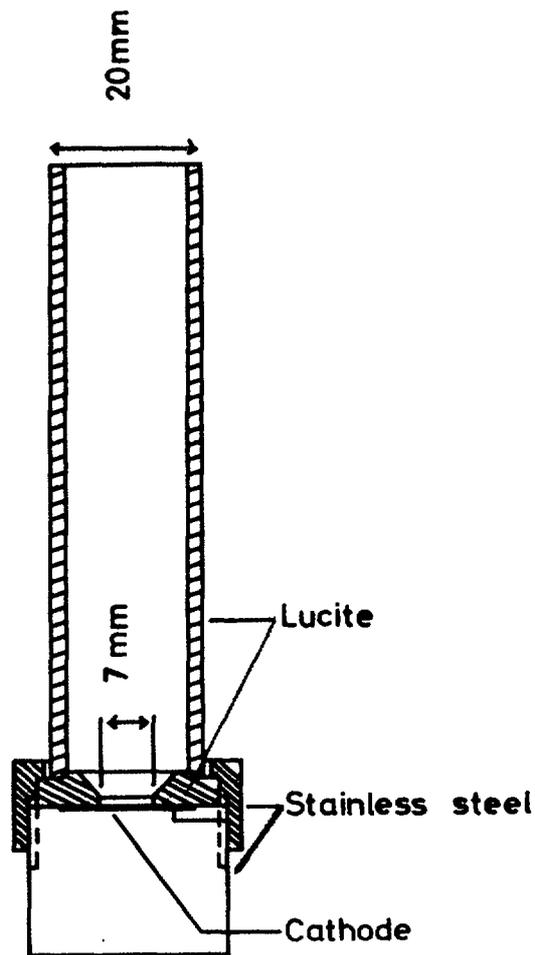


Fig. 1. Electrodeposition cell

Plutonium was stored in 2 M HNO_3 , i. e., as a mixture of oxidation states with the tetravalent ion as the dominant one. An essentially pure solution of a particular oxidation state was prepared by the following processes:

Pu(III) was prepared by the addition of sulphur dioxide or hydroxylamine to the sample.

Pu(IV) was obtained by treating the reduced sample with strong HNO_3 .

Pu(VI) was prepared by keeping a solution of 1 M HNO_3 and 0.1 M KBrO_3 at 95 °C for 4 h [19].

All the initial experiments were performed with plutonium in the tripositive state in the starting solution. No mechanical stirring was used,

and no intentional temperature regulation of the electrolytes was done during the electrodeposition.

The deposit formed from the acid solution will redissolve if the current is turned off while the electrodes remain in the solution. This was circumvented by adjusting the solution to an alkaline pH before interruption of the current, or the cathode was removed from the solution with the voltage on.

The stainless steel discs used were not polished but only cleaned in a solution of 2 % HF and 15 % HNO₃ at 60 °C for about 10 minutes. After dismantling the cell, the disc was washed with water and acetone and dried.

The electroplated samples were counted with a silicon surface barrier detector in conjunction with a scaler or a multichannel analyser. In all measurements in the present work, enough counts were taken to give a standard deviation of less than 3 %.

The plate uniformity was studied by means of radioautographs and densitometer readings.

4. Results and discussion

4.1 -- Addition of NH₃

Different amounts of NH₃ were added and the solution was made acid (pH about 2) with nitric acid. A known amount of plutonium was added, and the pH of the 12 ml solution was adjusted to 1.2 with nitric acid. As indicated in Fig. 2, high recoveries were obtained when the solution was 0.1 - 0.2 M in NH₃. Recoveries were inconsistent at low NH₃ additions. The mean value of 10 experiments with no NH₃ addition was 67 ± 30 %.

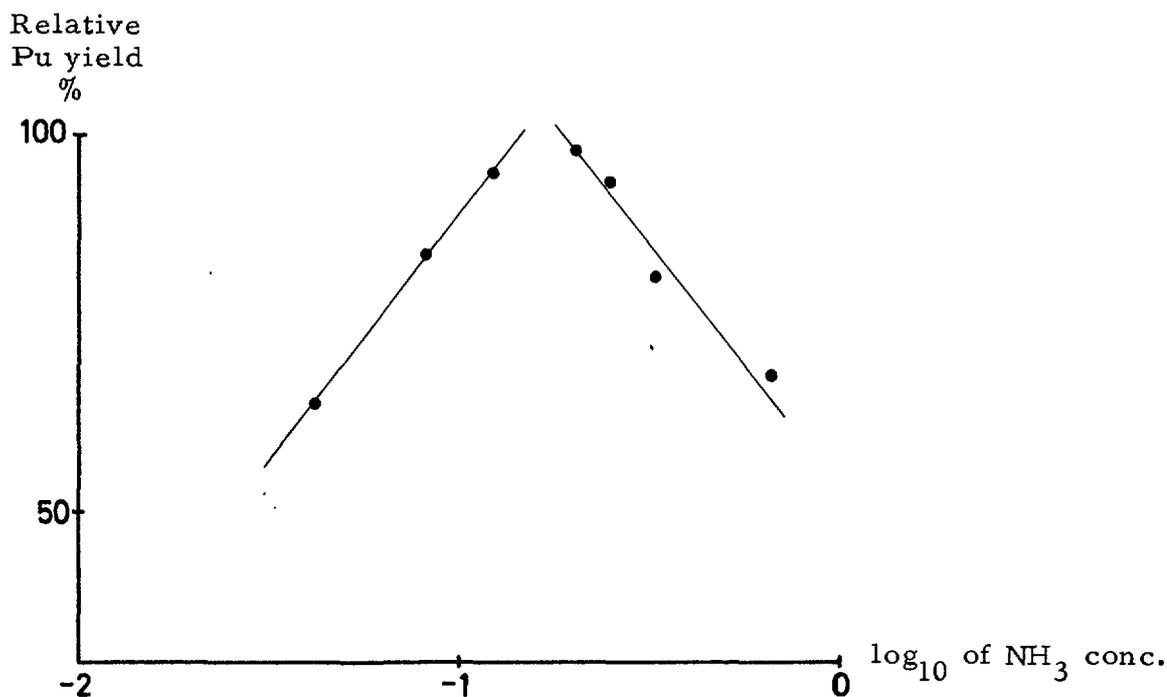


Fig. 2. Relation of plutonium yield to added NH₃ pH adjusted with nitric acid to 1.2; plating at 250 mA for 2.5 h

The following investigation was carried out with the electrodes 5 mm apart. 1 ml 2 M NH₃ was added to the 12 ml electrolyte, and the pH was adjusted to an appropriate value. The electrolyte was made alkaline with NaOH before interruption of the current at the end of electrolysis.

4.2 Acid concentration

Fig. 3 shows the variation of plutonium yield with the pH of nitrate solutions. The maximum yield was observed at pH 1.2 when the plating current was 400 mA. At lower currents the curve flattens and the maximum yield is obtained at somewhat higher pH. The electrolyte remains acid during the electrolysis, but the hydrogen ion concentration diminishes due to cathodic reduction of nitrate. Thus it was observed that the equilibrium pH of the solution increased from 1.20 to 1.35 after electrolysis for two hours at 400 mA.

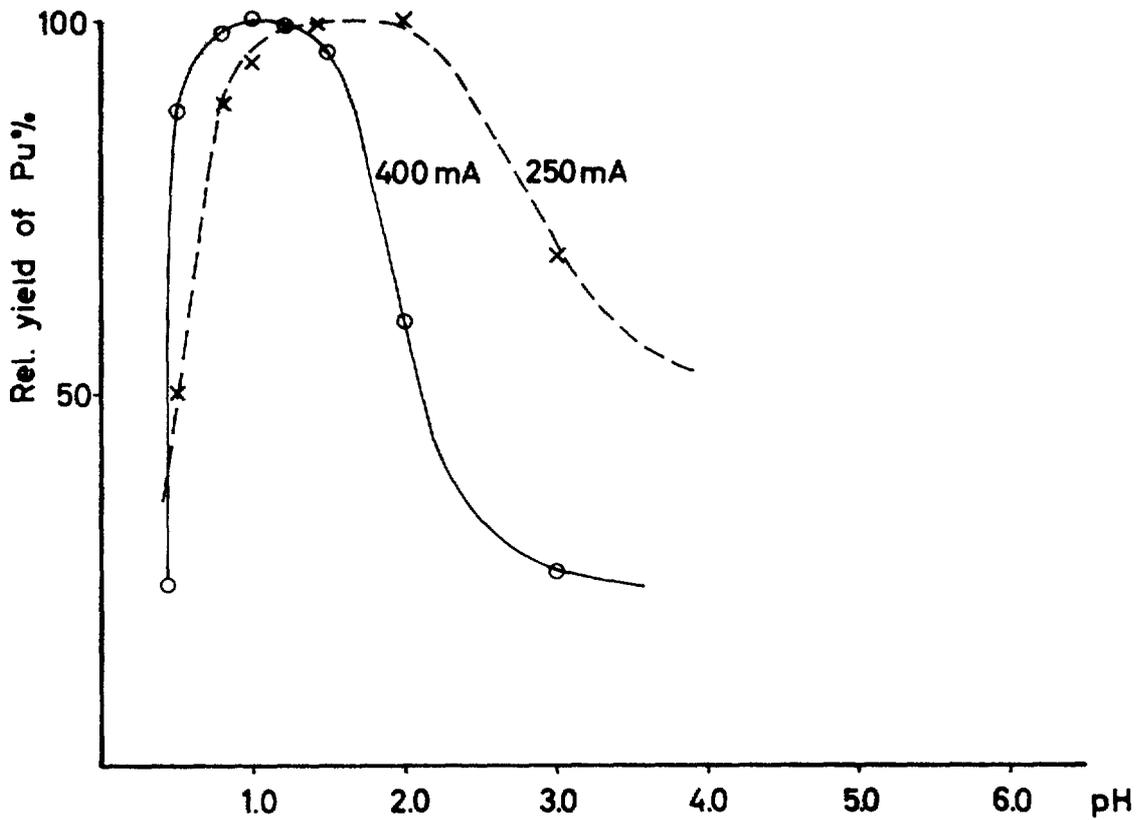


Fig. 3. Relation of plutonium yield to pH of the electrolyte
Electrolysis time: 2 h

4.3 Effect of current and electrolysis time on deposition yield

As shown in Figs. 4 and 5, high current is required for quantitative deposition in a short time. At the trace concentration of plutonium ions (about 10^{-8} M) studied, with an electrode area of 0.38 cm^2 , no useful increase in deposition rate is obtained by increasing the current density beyond about 1.1 amp/cm^2 .

Several experiments at 300 to 500 mA showed that the same deposition yield was obtained with different cathode areas (0.38 cm^2 and 2.0 cm^2) but with the same depth and volume of electrolyte. Apparently, the current rather than the current density is of significance under the special conditions tried.

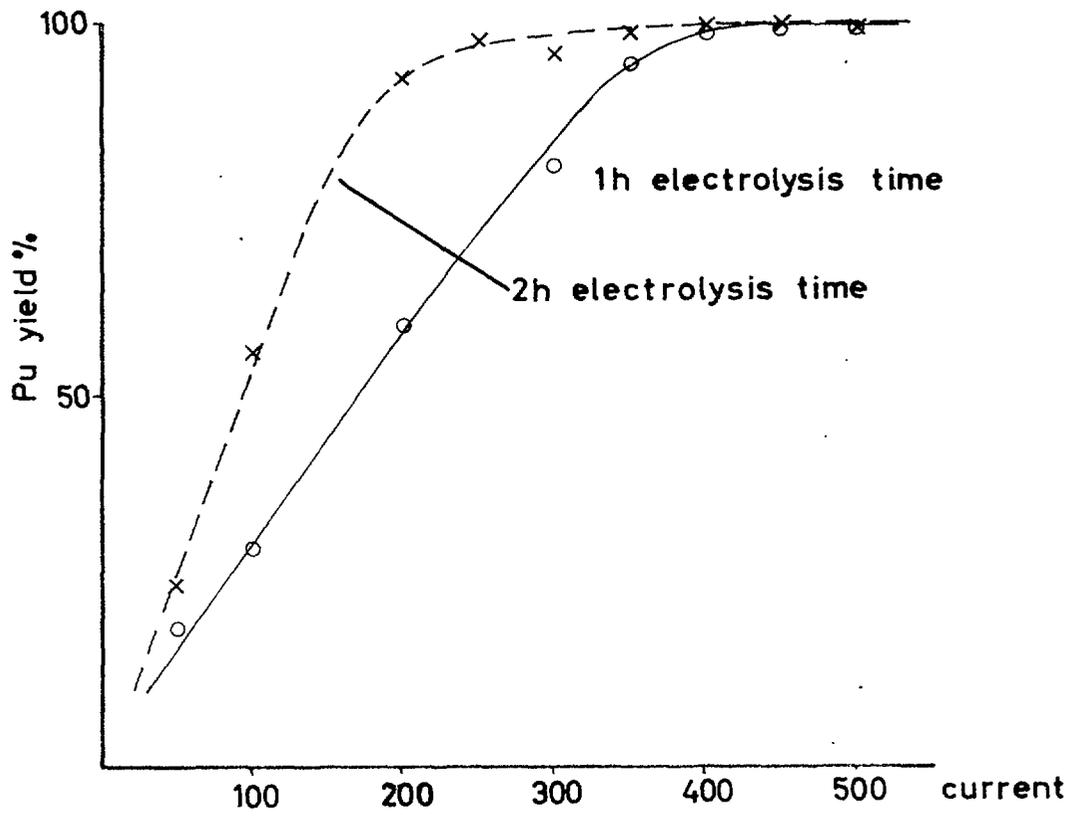


Fig. 4. Effect of current on electrodeposition of plutonium

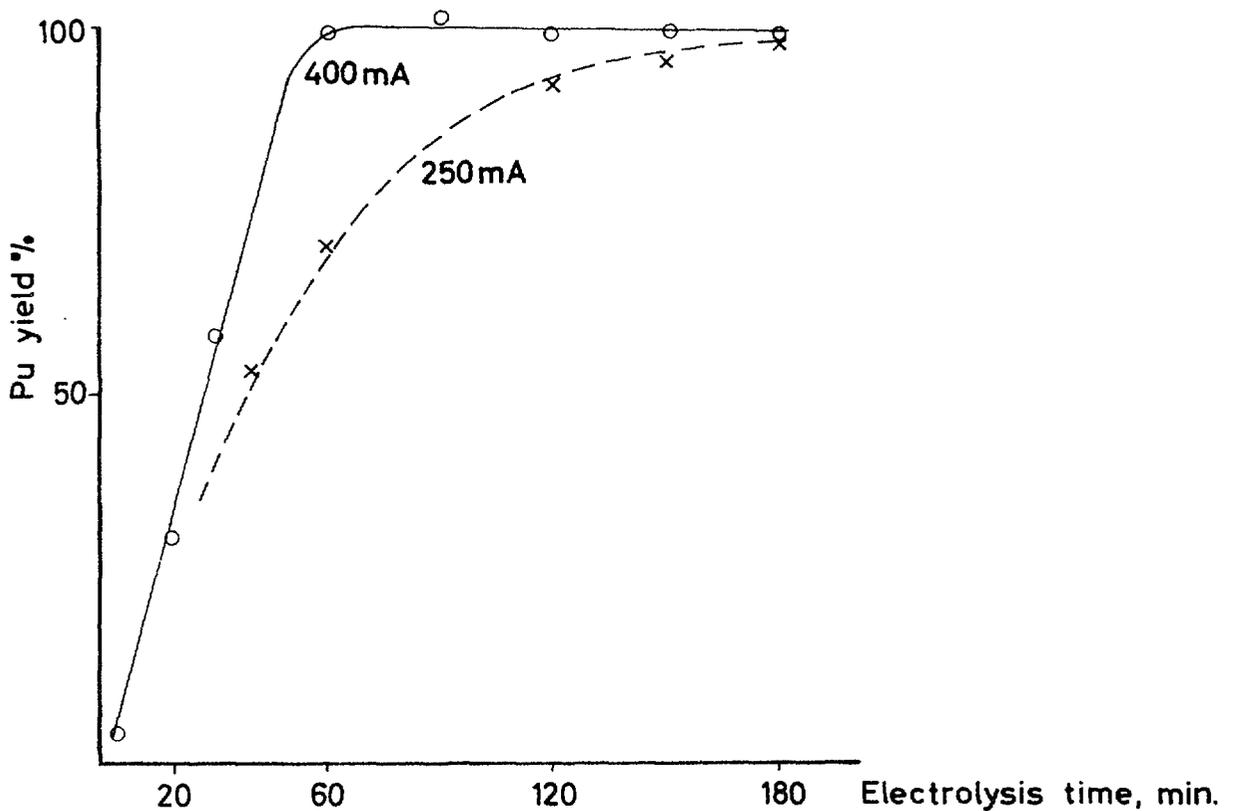


Fig. 5. Relation of plutonium yield to electrolysis time
pH = 1.2

It seems likely, as pointed out by Hansen [20, 21], that the rate-determining process is the transport of the solid phases formed by hydrolysis of the plutonium ions at the outer boundary of the "hydroxyl ion layer" through this layer to the cathode. The thickness of this layer is known to vary with the amount of stirring [22]. As it is difficult to imagine a more efficient method of stirring the liquid near the cathode than by rapid electrolytic evolution of hydrogen at the cathode, the thickness of the pH gradient should decrease as the current increases. Thus the increase in the deposition rate obtained by an increase in the current is caused mainly by an increase in the stirring of the catholyte.

4.4 Effect of mechanical stirring

The deposition of plutonium was studied at various rates of mechanical stirring by use of a rotating anode-stirrer (Fig. 6). As seen in Fig. 7, this type of applied stirring did not have any pronounced effect on the deposition rate. The reduced deposition rate observed at higher stirring rates is probably an effect of gas bubbles gathering between the cathode and the rotating anode and thus interrupting the current for short intervals.

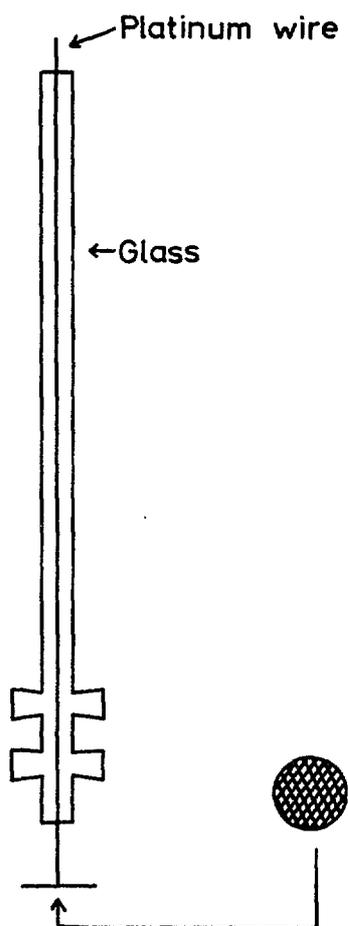


Fig. 6. Anode-stirrer

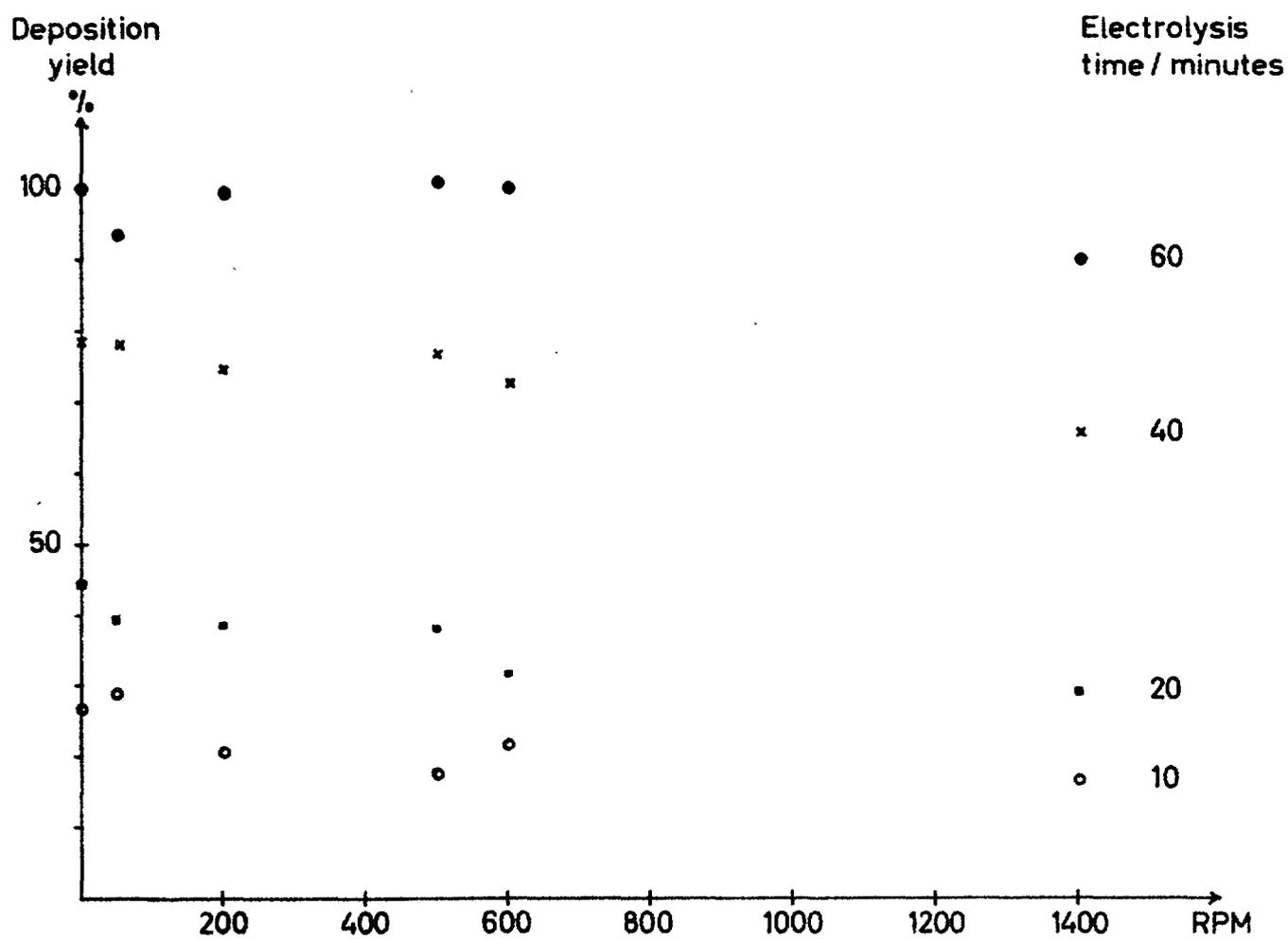


Fig.7 Effect of mechanical stirring on deposition rate.

pH=1,2; current: 400 mA

4.5 Effect of temperature

As shown in Figs. 4 and 5, a quantitative yield of plutonium was obtained by electrolysis at 400 - 500 mA for one hour. The potential applied to the cell was 12 - 14 V and the temperature in the electrolyte measured at the end of the electrodeposition was 56 - 59 °C. To get an indication of the influence of the temperature on the deposition, several experiments were carried out at different currents with the 12 ml cell immersed in an ice-bath.

Table 1. Deposition of plutonium at different currents with the cell immersed in an ice-bath.

pH 1.2; electrolysis time 70 min.

Current mA	Temp. at the anode measured after 60 min. °C	Yield %
100	6.5	22
200	9.5	40
350	15.0	97
400	22.0	101
500	26.2	100

Lower yields were obtained with cooling (Table 1) at the lower currents than without (cf. Fig. 4), but the deposition was in both cases quantitative at about 400 mA, and there seemed to be no difference in the adherence of the deposits.

4.6 Selected method for quantitative deposition of plutonium

From the results obtained the following conditions were selected for the quantitative isolation of plutonium from 6 - 12 ml of a mixture of nitric acid and ammonium-nitrate on a cathode of stainless steel.

- 1) Distance between the electrodes 5 mm
- 2) 1 ml 2 M NH₃ is added to the sample
- 3) Solution pH 1.2 is adjusted with nitric acid.
- 4) Current 450 - 500 mA

- 5) Electrolysis time 60 - 80 min
- 6) Before interruption of the current at the end of electrolysis 1 ml 6 M NaOH is added to prevent the precipitate from dissolving.
- 7) After dismantling the cell the disc is washed with small quantities of water and acetone and dried under a heating lamp.

The procedure was tested by electrodepositing plutonium from pure solutions of Pu(III), each containing 350 dis/min ^{239}Pu . For 50 plates an average of 99 % of the plutonium was deposited with a standard deviation of ± 5 %. The precision obtained in deposition of plutonium and neptunium when the counting error was reduced to 0.3 % (the plates were counted to a total of 10^5 counts) is shown in Table 2.

Table 2. Precision obtained in quantitative deposition of ^{239}Pu and ^{237}Np .

^{239}Pu cpm (platinum cathodes)	^{239}Pu cpm	^{237}Np cpm
	(stainless steel cathodes)	
11729	12873	4248
11684	12604	4276
11946	12727	4302
11945	12840	4211
11732	12789	4214
Mean 11807	12766	4250
Rel. dev. 1.1 %	0.83 %	0.92 %

The deposits were grey to dark grey in colour and adhered well to the plate. It was demonstrated by rubbing the plate with a filter paper that the deposit adhered much more strongly after oxidation in a muffle furnace at 450 °C for 20 minutes. This is, however, not a necessary step with submicrogram quantities of plutonium.

4.7 Surface preparation effects

Electropolished, acid-pickled and mechanically polished (to mirror finish) stainless steel cathodes were tried with the plating procedure described. The tests did not reveal any effect of surface preparation on

the deposition yields. Densitometer readings on autoradiographs of flamed electroprecipitated sources of 0.05 μg Pu on electropolished and acid-pickled cathodes did not reveal any difference in the uniform distribution of plutonium on the surfaces. It was, however, observed that deposition on acid-pickled discs resulted in cleaner deposits as compared to electropolished and especially mechanically polished surfaces, which may be due to better resistance of the acid-pickled surface to chemical changes during the electrolysis.

4.8 Cathode materials

Nickel, tantalum, silver and platinum were tried as cathode materials. The yield and quality of the deposited plutonium sources were not significantly different from those obtained with stainless steel as cathode material.

It was observed during the experimental work that electrodeposition at higher hydrogen ion concentrations and high currents often gave black, nonadherent deposits with poor plutonium recovery. As this interference was found under the same conditions with all cathode materials tried, it is assumed to be an effect of dissolution of the platinum anode.

4.9 Deposition from various acids

Table 3 shows the percentage plutonium (III) deposited from various acids when electrolysed according to the established method. HNO_3 , HCl , HClO_4 and H_2SO_4 were all found to be good electrolytes for plutonium deposition, but not so H_3PO_4 or $\text{H}_2\text{C}_2\text{O}_4$, which may be an effect of the stronger complexing properties of these anions.

Table 3. Electrodeposition of plutonium from various acids and in different oxidation states. pH 1.2; current 450 - 500 mA; electrolysis time 60 min.

Number of experiments	Acid	Oxidation state of Pu in the starting solution	Recovery %
50	HNO ₃	III	99
2	HNO ₃	IV	99
4	HNO ₃	VI	98
2	HCl	III	96
3	HClO ₄	III	97
3	H ₂ SO ₄	III	94
2	H ₃ PO ₄	III	70
2	H ₂ C ₂ O ₄	III	11

4.10 Deposition of plutonium in different oxidation states

Experiments with plutonium in different oxidation states in nitrate solution by the procedure described showed quantitative deposition of the plutonium (Table 3) regardless of its oxidation state in the starting solution. The electrolysis is performed several volts above the thermodynamic potentials for reversible or irreversible transitions between the different oxidation states of plutonium, which makes it difficult to predict which oxidation state should be the most favourable one for the complex process of non-metallic plutonium deposition. This holds as long as the pH in the bulk solution is maintained in the region of acidity at which hydrolysis of plutonium does not occur.

4.11 Electrolytic precipitation of plutonium in the presence of foreign ions

Small amounts of foreign elements forming hydrolysis products with colloidal properties in the alkaline region near the cathode have been reported [5, 7, 13] to interfere strongly with the deposition of plutonium.

Electrodeposition of plutonium from solutions containing 0.5 - 10 mg of iron or aluminium resulted in very low recoveries of the plutoni-

um. Oxalic acid was added in various amounts to the iron - containing electrolytes to complex the iron, but the attempts were without any apparent success.

Inert salts such as alkali nitrates were added to the electrolyte in quantities up to 50 mg without adversely affecting the deposition of plutonium.

4.12 Electrodeposition of uranium, neptunium, americium, cerium and thulium

The plating conditions selected for deposition of plutonium were also tried with U, ^{237}Np and ^{241}Am (Table 4).

Considering that plutonium (III) and the rare earths have similar electrochemical properties, it was assumed that the same method would be suitable for electrodeposition of the rare earth elements. This was found to be the case for cerium and thulium, which were selected to represent both ends of the lanthanide series. Electrodeposition of cerium was, as seen in Table 4, effective only in the presence of some reducing agent. Hydroxylamine hydrochloride was used to ensure that the cerium was in the tripositive state.

Table 4. Electrodeposition of U, Np, Am, Ce and Tm.

Element	Recovery (%) (Mean of 5 - 10 experiments)
U	98.2 ± 1.3
^{237}Np	99.1 ± 1.1
^{241}Am	95 ± 3
^{144}Ce	61 ± 6 without reducing agent
^{144}Ce	96 ± 3 with 50 mg hydroxylamine hydrochloride
^{170}Tm	98 ± 2

5. Electrolytic precipitation of mg amounts of plutonium and neptunium

The method worked out for electrodeposition of plutonium was also tried for plating up to mg amounts of ^{239}Pu and ^{237}Np on small stainless steel rods intended for use as anodes in absolute fission counters. The electrodes were cylinders 3 mm in diameter and 22 or 32 mm long, of which 10.0 or 20.0 mm were to be coated with known amounts of fissionable materials.

The technique used for accurate determination of the quantity of material included preparation of solution of known composition, electrodeposition, and then performance of a material balance by alpha assay of the residual solution. The plating cell arrangement is shown in Fig. 8. All parts of the cathode except the surface to be plated are covered with plastic tubing. The anode is a length of platinum wire wound into a spiral 25 mm long and 10 mm in diameter. To avoid uneven coating on account of the cathode not being too well centered inside the anode spiral, the cathode was slowly rotated (80 rpm).

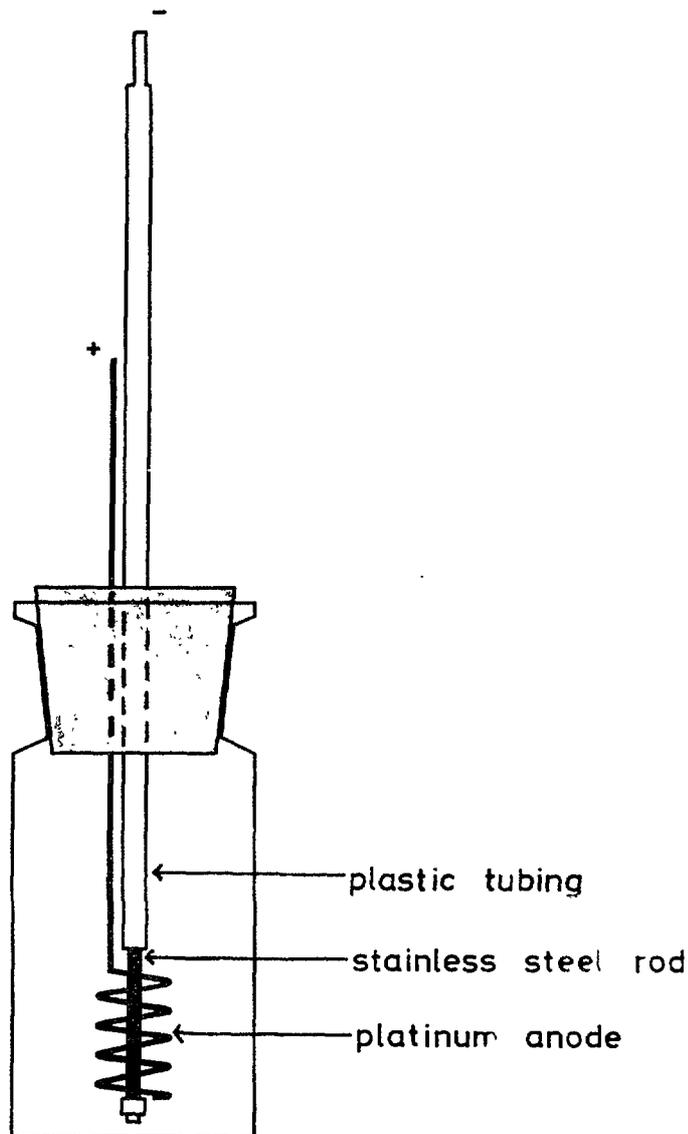


Fig. 8. Cell arrangement used for plating Pu and Np on small stainless steel rods

Initial experiments resulted in good recoveries also of weighable amounts of plutonium when plated on the small stainless steel cylinders. The deposits, however, became rather grainy, flaky and non-adherent. Decrease of current alone did not appreciably improve the quality of the deposit but increased the electrolysis time.

It has been reported [2, 11] that macroscopic deposits formed cathodically from alcohol-acetone solutions are more uniform and adherent than those formed from aqueous solutions. Different mixtures of alcohol, acetone and water were tried. A quite satisfactory improvement of the film quality was obtained by using an electrolyte consisting of 50 % alcohol, 40 % acetone and 10 % water. Electrolysis at 400 mA of such solutions with pH adjusted to 1.2 with nitric acid removed 75 % or more of the added plutonium (0.2 - 1 mg) in one hour, and about 90 % was plated in 3 h. As this recovery was satisfactory for the purpose in view, and the yellow-brown films obtained were sufficiently uniform and adherent, no further attempts were made to increase the element yield.

The same plating conditions were used for plating up to 2 mg of neptunium.

The uniformness of the films was analysed by alpha counting under well defined source-detector geometry on 20 points distributed over the coated surface. A collimator ($\phi \approx 1$ mm) was inserted between the source and the solid state detector.

A typical result is shown in Table 5.

Table 5. Check of the uniformity of an electrodeposited layer of 1.01 mg ^{237}Np on a small stainless steel rod ($\phi \approx 3$ mm; $l \approx 20$ mm) by means of alpha counting.

	Counts per minute				
	298	267	303	256	230
	325	260	273	310	264
	290	254	301	309	303
	323	276	269	276	323
Total:	5710				
Mean:	286				
Rel. std. dev.	9.3 %				

Acknowledgement

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References

1. MEITNER, L,
Über einige Einfache Herstellungsmethoden Radioaktiver
Zerfallsprodukte.
Physik Z 12 (1911) 1094.
2. HAISSINSKY, M,
Electrochimie des substances radioactives et des solutions
extrêmement diluées.
Actualités Scient., 1946 no. 1009.
3. MILLER, H W and BROUNS, R J,
Quantitative Electrodeposition of Plutonium.
Anal. Chem. 24 (1952), 536.
4. MOORE, F I. and SMITH, G W,
Electrodeposition of Plutonium.
Nucleonics 13 (1955), 66.
5. The Determination of Plutonium in Urine. 1958.
(La-1858 2 ed.) p. 155.
6. KO, R,
The Electrodeposition of Plutonium from Acid Solution. 1954.
(HW-32673).
7. SAMARTSEVA, A G,
Electrolytic Isolation of Small Amounts of Uranium, Neptunium
Plutonium, and Americium.
Sovj. J. Atomic. Energy 8 (1961) 279.
8. LOVERIDGE, B A,
Quantitative Electrodeposition of Plutonium for Alpha and
Beta Assay. 1960.
(AERE-R3266).
9. SANDERS, S M and LEIDT, S C,
A New Procedure for Plutonium Urinalysis.
Health Physics 6 (1961) 189.
10. MITCHELL, R F,
Electrodeposition of Actinide Elements at Tracer Concentrations.
Anal. Chem. Vol. 32 (1960) 326.
11. DEDOV, V B and KOSYAKOV, V N,
Electrodeposition of Plutonium, Americium and Curium.
Proc. Int. conf. peaceful uses of atomic energy. Geneva 1955.
New York 1956, Vol. 7 p. 369.
12. DONNAN, M Y and DUKES, E K,
Carrier Technique for Quantitative Electrodeposition of Actinides.
Anal. Chem. Vol. 36 (1964) 392.

13. SMITH, G and BARNETT, G A,
The Quantitative Electrodeposition of Tracer Protactinium. 1964.
(AEEW-R386).
14. PARKER, W and FALK, R,
Molecular Plating: A Method for the Electrolytic Formation of
Thin Inorganic Films.
Nucl. Instr. and Meth. 16 (1962) 355.
15. PARKER, W,
Methods in the Preparation of Radioactive Material. Gothenburg
1965. Thesis, Inst. of Physics, Chalmers University of Tech-
nology.
16. GVOZDEV, B A and CHUBURKOV, Yu T,
Preparation of Layers of Oxides of Th, U, Pu, and the Rare
Earth Elements by Electrodeposition from Organic Solutions.
Sovj. Radiochemistry 5 (1963) 673.
17. LATIMER, W M,
Oxidation Potentials.
2 ed., Prentice Hall N. Y. 1952.
18. COATES, G E,
Concentration Polarization in Acid Solutions.
J. Chem. Soc. 1945, 484.
19. CARLESON, G,
The Extraction of Plutonium at Various Oxidation Potentials.
(P/137). Proc. Int. conf. peaceful uses of atomic energy.
Geneva 1958, Vol. 17 p. 111.
20. HANSEN, P G,
The Conditions for Electrodeposition of Insoluble Hydroxides
at a Cathode Surface: a Theoretical Investigation.
J. Inorg. Nucl. Chem. 12 (1959) 30.
21. HANSEN, P G,
The Electrodeposition of Insoluble Hydroxides: an Experimental
Investigation.
J. Inorg. Nucl. Chem. 17 (1961) 232.
22. KING, C V,
Concentration Polarization and Overvoltage.
J. Electrochem. Soc. 102 (1955) 195.

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